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# Effects of Extrusion Variables on Functional and Nutritional Properties of Extruded Oat Products

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## Abstract

**The purpose of this research was to study the effects of initial moisture levels and extrusion temperatures on dietary fiber, nitrogen solubility index, available lysine, and the *in vitro* protein digestibility of extruded oat products. The dehulled grains were ground in a Brabender Quadrumat Senior mill and the coarse fraction, with higher crude protein, lipids and dietary fiber were conditioned to various moisture levels (15.5~25.5%) and extruded in a Brabender single-screw laboratory extruder. The extrudates showed a higher amount of soluble dietary fiber (8.14%) than in the raw material. However, the extrusion process affected the nutritional value of the protein due to a decrease in available lysine with increased temperature. The *in vitro* protein digestibility was unaffected by initial moisture levels and the extrusion temperatures examined.**

**Key words:** oat (*Avena sativa* L), extrusion, digestibility, lysine

## INTRODUCTION

Although one of the purposes of heat treatment is to inactivate enzymes which cause the rancid and bitter taste of oat products, the same process also improves the product taste and partially gelatinizes the starch. Heat treatment must be mild to avoid speeding the oxidation process that leads to a rancid taste or to a decrease in the nutritional value of oat products (1).

The heat treatment in starch-rich materials induces physical and chemical modifications of the starch granules and their components, leading to changes in texture and rheology, increasing starch digestibility and availability as a source of energy (2). Depending on the processing conditions and the composition of the material in use, the starch granules can expand and break their crystalline spectrum and their solubility in cold water is modified, the viscosity is reduced, and complete release of amylose and amylopectin can occur (3).

Camire and Flint (4) studied the effect of cooking by extrusion and by a conventional process on dietary fiber composition and hydration capacity of corn flour, oat, and potato peels. The total amount of insoluble fiber in oat flour increased in both processes, but the ratio of soluble to insoluble fiber was higher in the products processed by extrusion. Gualberto (5) observed that extrusion conditions did not affect the phytate contents of oat products, but it did alter the amount of dietary fiber as the screw speed was changed.

The protein structural changes observed during extrusion occur in a sequence, through denaturing, association, rupture of some or all the associations by heat, and shear force. The formation of a concentrated solution or the melted phase, and possible formation of some covalent bindings at high temperatures, non-covalent and di-sulfate bindings under cold and transition of amorphous regions into a vitreous state is possible if the moisture level is sufficiently low (6).

Srihara and Alexander (7), evaluating the effect of heat by extrusion and by microwaves on the protein quality of five composed flours, verified that both treatments improved flour quality, although this was higher in flours processed by extrusion. McAuley et al. (8) observed that cereal flakes processed by extrusion presented a lower loss of available lysine than those processed by flaking.

This research was done to study the effects of initial moisture levels and extrusion temperatures on dietary fiber, nitrogen solubility index, the amount of available lysine, and the *in vitro* protein digestibility of extruded oat products.

## MATERIALS AND METHODS

### Materials

Oat grains of the UPF 16 cultivar, obtained from the University of Passo Fundo breeding program, were used in this research. The grains were cleaned by airing and sieving. The husks were removed by an impact milling machine. The caryopse were dried to 10% moisture and milled in an experimental roll mill (Brabender Quadrumat Senior Mill) using the break section and sieving system.

The samples were conditioned to various moistures (15.5, 17, 20.5, 24, 25.5%) and processed in a Brabender extruder (model 20D/N-GNF 1014/2, Brabender OHG, Duisburg, Germany) of the single screw type, operated at 3:1 compression rate, 100 rpm, 6 mm-diameter matrix, and 70 g/min-constant input. The temperature was 80°C in the first zone and 77.6, 90, 120, 150 and 162.4°C in the second and third zones.

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The extruded products were dried in a laboratory oven with air circulation, at 45~50°C for 15 hours, milled in a mill of knives and rolls (<500 μm) and packaged in plastic bags of low density polyethylene (70-μm thick). The bags were stored at room temperature (25°C±2), protected from light, until analyses.

**Functional and nutritional properties analyses**

The content of dietary fiber was determined in the aspect of insoluble, soluble, and total fiber according to the AACC method number 32-21 (9). Four replicates of each sample were gelatinized in the presence of heat stable α-amylase (Sigma-A3306) and were digested with protease (Sigma-P3910) and amyloglucosidase (Sigma-A9913) to remove proteins and starch. The results were expressed in percentages.

Nitrogen solubility index was assessed according to the AACC method number 46-23 (9). Five grams of a ground sample (<80 mesh) were dispersed in 200 ml of distilled water at 30°C and were shaken mechanically at 120 rpm for 120 minutes. The solubility index, expressed in percentages, was determined based on the ratio between water soluble and total nitrogen in the sample.

The available lysine was measured as described by Kakade and Liener (10) using 0.1% TNBS in water. The amount of lysine was quantified from samples dissolved in 4% $NaHCO_3$ using the Lambert Beer's colorimetric equation and the 1.46 $\times 10^4 M^{-1} \times cm^{-1}$ coefficient of molar extinction (E).

*In vitro* protein digestibility was assessed based on Akeson and Stahmann (11) by digesting the samples with pepsin and pancreatin. The hydrolyzed material was then separated from the non-digested (solid) fraction by precipitation in 30% trichloroacetic acid and by further centrifugation. The same process was used to obtain enzyme and sample whites. Protein digestibility was based on the amount of nitrogen in the hydrolyzed portion, which was obtained by micro- Kjeldahl.

**Experimental design and statistical analysis**

To study the combined effect of independent variables (moisture content and extrusion temperature), a statistical design of rotational composed central type, of 2nd degree, applied to a surface response methodology (12) was used. The independent variables and variation levels studied are presented in Table 1. In this experiment 11 treatments were tested, four factorial (combining the levels -1 and +1), four axial (one variable at and $\pm\alpha$ one at zero), and three central (two variables at zero).

Statistical data were analyzed in SAS (13). The model significance was tested using ANOVA while the individual effects of the response variables were adjusted through a stepwise procedure at 10% significance level ($p \leq 0.10$). The insignificant elements were dropped from the model and this was subjected to new analyses.

**Table 1.** Variables and levels of variation of the extrusion experiment

| Independent variables | Levels of variation[1)] | | | | |
|---|---|---|---|---|---|
| | $-\alpha$ | -1 | 0 | +1 | $+\alpha$ |
| Extrusion temperature (°C) | 77.5 | 90 | 120 | 150 | 162 |
| Moisture content (%) | 15.5 | 17 | 20.5 | 24 | 25.5 |

[1)] $\alpha$=1.414 for k=2 (two independent variables).

## RESULTS AND DISCUSSION

**Dietary fiber**

Extrusion can alter content, composition, and the physiological effects of dietary fiber. Degradation of dietary fiber to low molecular weight fragments reduces its content, thus diminishing its benefits. In contrast, macromolecular degradation increases fiber solubility and changes its physiological effects (2,14). However, the results of extrusion effects on dietary fiber are still inconclusive; much of such controversy is attributed to the use of different analysis protocols (12).

The mean values for soluble dietary fiber, insoluble fiber, and total fiber for extruded oat products were 8.14, 8.95 and 17.09%. The mean value for soluble dietary fiber was higher in the extrudate (8.14%) than in the raw material (6.92%). Conversely, the amount of insoluble fiber was lower (8.95% vs. 9.90%). Therefore, there was an average 8% increase in soluble dietary fiber in the extruded oat products (Table 2). Similar findings were observed by Oda et al. (15) when studying modifications of dietary fiber in the oat extruded, which suggests that some insoluble components become soluble during extrusion.

Lue et al. (14) verified that dietary fiber content did not vary significantly and the starch gelatinized completely after extrusion of corn-beet composed flour (0~30%). The authors also observed that the amount of dietary soluble fiber increased over that of the raw material. Berglund et al. (16) evaluated the properties of some extruded cereals with high fiber contents and observed the increase in dietary soluble fiber in the range of 5 to 64%, depending on the initial contents present in the raw material. Overall, the insoluble

**Table 2.** Experimental data of soluble fiber, insoluble fiber, nitrogen solubility index (NSI), available lysine and the *in vitro* protein digestibility for extruded oat products

| N° | Variables[1)] | | Determination | | | | |
|---|---|---|---|---|---|---|---|
| | T | U | Soluble fiber (%) | Insoluble fiber (%) | NSI (%) | Lysine g/16 g N | Digestibility (%) |
| 1 | 90 | 17 | 8.37 | 9.19 | 5.87 | 1.20 | 81.15 |
| 2 | 150 | 17 | 7.84 | 9.17 | 4.41 | 0.72 | 78.10 |
| 3 | 90 | 24 | 8.06 | 8.92 | 7.07 | 1.18 | 82.75 |
| 4 | 150 | 24 | 8.07 | 8.91 | 5.46 | 0.51 | 69.92 |
| 5 | 77.6 | 20.5 | 8.43 | 9.02 | 8.50 | 1.61 | 70.65 |
| 6 | 162.4 | 20.5 | 8.06 | 8.25 | 4.28 | 0.54 | 85.85 |
| 7 | 120 | 15.5 | 8.18 | 9.04 | 4.73 | 0.56 | 90.20 |
| 8 | 120 | 25.5 | 8.10 | 9.05 | 5.64 | 0.65 | 70.76 |
| 9 | 120 | 20.5 | 7.92 | 9.06 | 4.97 | 0.59 | 85.18 |
| 10 | 120 | 20.5 | 8.32 | 8.92 | 4.68 | 0.65 | 86.83 |
| 11 | 120 | 20.5 | 8.16 | 8.91 | 4.92 | 0.60 | 85.90 |
| Raw material | | | 6.92 | 9.90 | 24.01 | 2.82 | 79.69 |

[1)] T=extrusion temperature (°C); U= moisture content of raw material (%).

dietary fiber decreased in all cereals. The increment in soluble fiber is due to a decrease in insoluble fiber, since the variation in total dietary fiber was relatively low.

**Nitrogen solubility index (NSI)**

The experimental values of determinations and adjusted regression model, as well as its coefficients of determination and significance levels, are found in Table 2 and Table 3, respectively. The linear and quadratic terms for extrusion temperature and the quadratic term for initial moisture were significant. The high coefficient of determination ($R^2$=0.92) indicates that the model explains most of the variation of the dependent variable. Therefore, the model equation is adequate to represent the solubility index for extruded oat products within the range of values studied in this research.

Fig. 1 represents the surface graphic associated with the adjusted regression model, which establishes the variation in nitrogen solubility index as a function of the extrusion temperature and moisture content of the raw material. As extrusion temperature increased and moisture content diminished, the NSI lowered. Moisture effect was less intense than that of the extrusion temperature. Lowest NSI values occurred in extrusion at 162.4°C and 15.5% moisture. In this study, relatively mild conditions were used, which differs from the data reported by Saio et al. (17), where increased heating caused proteins to reach minimum NSI very quickly. From such a point, it is postulated that protein degradation began and caused the associated increase in solubility. The speed of such reactions is proportional to intensity of heat treatment.

**Table 3.** Regression model, coefficient of determination ($R^2$), and significance level for nitrogen solubility index (NSI), and available lysine for extruded oat products

| Response | Model[1)] | $R^2$ | Prob>F |
|---|---|---|---|
| NSI | $y=19.595-0.2284T+0.0008T^2+0.0031U^2$ | 0.9200 | 0.003 |
| Lysine | $y=5.8498-0.0759T+0.00027T^2$ | 0.9591 | 0.0001 |

[1)]T=extrusion temperature (°C); U=moisture content of raw material (%).

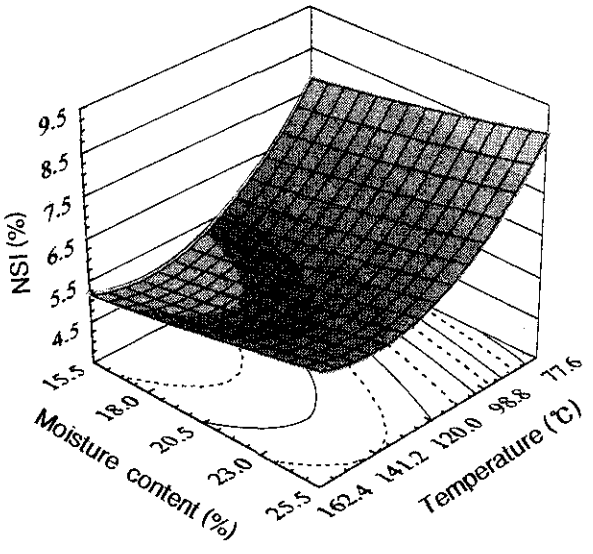


**Fig. 1.** Effect of the moisture content and extrusion temperature on the nitrogen solubility index (NSI) for extruded oat products.

**Available lysine**

Lysine is a limiting amino acid in many vegetal proteins, availability of which is a quality indicator of the product being examined (8). The amino acid availability is largely varied and depends not only on the protein itself but also on the type of treatments to which the food is subjected (18). One of the mechanisms responsible for reduced availability of amino acids is the Maillard reaction, which diminishes lysine availability (19). Studies on extrusion-cooking effects over amino acids have concentrated on lysine. According to Noguchi et al. (20), increase in extrusion temperature resulted in lower lysine availability. Also, higher moisture content in the raw material caused a higher lysine retention.

The amount of available lysine varied significantly ($p \leq 0.05$) as a function of extrusion temperature. Adequacy of the adjusted model is shown by the coefficient of determination, which explains 0.96 of the dependent variable total variance. Based on such results, the equation in Table 3 is adequate to predict available lysine behavior for extruded oat products within the range of studied values. Whereas the amount of available lysine in the raw material was 2.82 g/16 g N, in the extruded materials the values ranged from 0.51 to 1.20 g/16 g N, which means 13.71 to 32.26% more lysine than the initial level (Table 2).

The variation in available lysine as a function of extrusion temperature is represented in Fig. 2. Lysine content diminished in a quadratic fashion as extrusion temperature increased. Such a fact was similar to that observed for NSI, except that initial moisture variable was not significant. The reduction in available lysine was around 60% at 90°C, but increased when the extrusion was carried at 120°C. These results agree with those obtained by Asp and Bjoerck (21) and by Mercier (19).

**The *in vitro* protein digestibility**

Digestibility is an important indicator to evaluate the nutritional value of the protein. Protein denaturation improves its digestibility as it facilitates the proteolytic action of some digestive enzymes. However, such processes enables protein

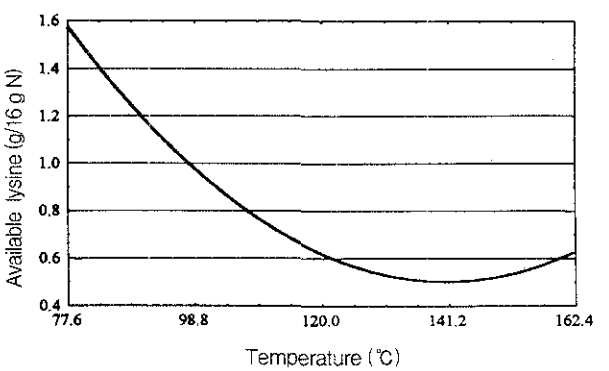


**Fig. 2.** Effect of extrusion temperature on available lysine for extruded oat products.

reactions or interactions with other food components, which may result in lowered nutritional value (18).

In extrusion under mild conditions, the nutritional value of vegetal proteins tends to increase due to modifications in the tertiary and quaternary third and fourth degree structures and protease inhibitors as well (19). However, extrusion carried out in severe conditions (temperatures at above 180°C) results in nutritional value reduction as well as diminished digestibility (2).

The analysis of variance for the protein digestibility results of extruded oat products shows that no variable was significant ($p>0.05$). The observed variation ranged from 70.65 to 90.20%, while it was 79.69% in the raw material. The use of intermediary temperatures (120°C) and low moisture levels resulted in higher protein digestibility, which agrees with a report by Dahlin and Lorenz (22) on *in vitro* protein digestibility for extruded cereals.

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